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Photochemical Air Pollution Damage Survey of Ponderosa Pine Within and Adjacent to Denver, Colorado: A Preliminary Report

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United States
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Forest Pest Management
Denver, Colorado

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ABSTRACT

Surveys were conducted within and adjacent to the Denver metropolitan area to locate photochemical air pollution injury on ponderosa pine. Trees southeast of Denver exhibited shortened needles and reduced needle complement. Chlorotic banding of foliage was occasionally found on trees within the areas surveyed. Confirmation of air pollution symptoms cannot be made without controlled exposure experiments coupled with more elaborate oxidant monitoring. Five evaluation plots were established near Denver to monitor oxidant injury on ponderosa pine over time.

INTRODUCTION

Denver, Colorado has an air pollution problem (Fig. 1). National Ambient Air Quality Standards (NAAQS)[1] have been exceeded for ozone, carbon monoxide, and particulates since 1965 when measurements began in downtown Denver (3).

Ambient air quality levels are influenced by many factors, such as amounts of pollutants emitted and local meterology. Denver has a dense emission pattern typical of an urban region dependent on an automobile commuting life style; the commuting fleet consists of 90 vehicles for every 100 commuters (3). Emissions consisting of oxides of nitrogen and hydrocarbons react with sunlight to form ozone (5, 12). Ozone is an unstable gas; natural background levels occur at low concentrations (0.05 ppm = 98 $\mu g/m^3$) and are variable depending on natural physical and chemical phenomena (9). Through a complex series of chemical reactions, ozone remains in a dynamic state and can be transported long distances from urban environments (3, 16).

Photochemical air pollution causes damage to a wide range of plants. Ozone injury to pine may result in chlorotic mottling, tipburn, and stunting of foliage (6, 26). Other indications of damage include reduced needle retention (18), deterioration of fibrous root systems (21), branch dieback (21), decreased height and diameter growth (20, 25), and premature aging (14). Air pollution injury may be confused with damage caused by fungal and viral pathogens, insects, and nuitritional deficiencies (4, 10). Environmental factors may also obscure air pollution injury (4).

Denver's climate is unique for a city of its size. Due to temperature inversions, Denver's pollutant cloud is usually concentrated in the morning, but highly dispersed by early afternoon after inversions break. Because Denver is on the east side of the Rocky Mountains, prevailing westerly winds do not result in containment of a pollutant cloud (3). Nearby mountain slopes, however, provide typical upslope-downslope diurnal wind patterns. Also common wind reversals may cause pollutants to reach mountains west of Denver.

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[1] National Ambient Air Quality Standard for ozone: The expected number of days per calendar year with a maximum hourly average greater than 0.12 ppm (235 $\mu g/m^3$) is equal to or less than one. This standard is new as of February 8, 1979 and replaces a more restrictive 0.08 ppm (157 $\mu g/m^3$) standard that was established April 30, 1971 (2).

FIGURE 1. Air pollution in Denver, Colorado. The Denver "brown cloud" as seen from the foothills looking toward downtown Denver during the morning.

Studies of air pollution climatology in California and other geographical locations indicate maximum ozone concentrations occur near midday and are directly related to solar intensity (11, 13, 15). In Denver, levels of ozone fall off rapidly in late afternoon with maximum levels occuring during the summer (2).

Six stations measure ozone in metropolitan Denver. Other stations in Colorado are located at Fort Collins, Greeley, Boulder, and Colorado Springs. Ozone levels monitored at Arvada, Boulder, and two stations in Denver (Jewish Hospital and Welby) were in violation of the NAAQS in 1978 (1). With the expection of Welby, ozone levels in 1978 were lower than in 1977. Number of NAAQS violations in 1978 were lower than those experienced in 1975 through 1977. Ozone levels in Denver have been more uniform in recent years (1).

Because ozone levels are sufficient in and around Denver to elicit plant response (1, 3, 19, 27), surveys were conducted to locate air pollution symptoms on trees within areas with the greatest damage potential.

MATERIALS AND METHODS

Survey areas (Fig. 2 - Table 1) were selected on the basis of presence of ponderosa pine (*Pinus ponderosa* Laws.)[2], proximity to the Denver metropolitan area, and accessibility. Foliage of ponderosa pine within selected areas was examined for typical oxidant air pollution symptoms. Number of trees examined at each site was tallied and general foliar condition noted. Trees were also examined for evidence of other diseases or insects. Trees possibly damaged by air pollution were photographed.

Five evaluation plots were established to monitor development of air pollution injury over time. Healthy trees without severe insect or disease injury were selected within plot areas. Each plot tree was measured (DBH, height), crown class determined, identified with an individual numbered tag, and rated for oxidant damage using systems formulated by Miller (17) or Pronos et. al (22). Complete descriptions of these rating systems are included in the Appendix. Each plot tree was photographed. Plots will be monitored at least biannually to document changes in foliar condition.

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[2] The survey was restricted to ponderosa pine because of its natural abundance near Denver and relative high susceptibility to oxidant air pollution injury reported in California studies (19, 21, 27).

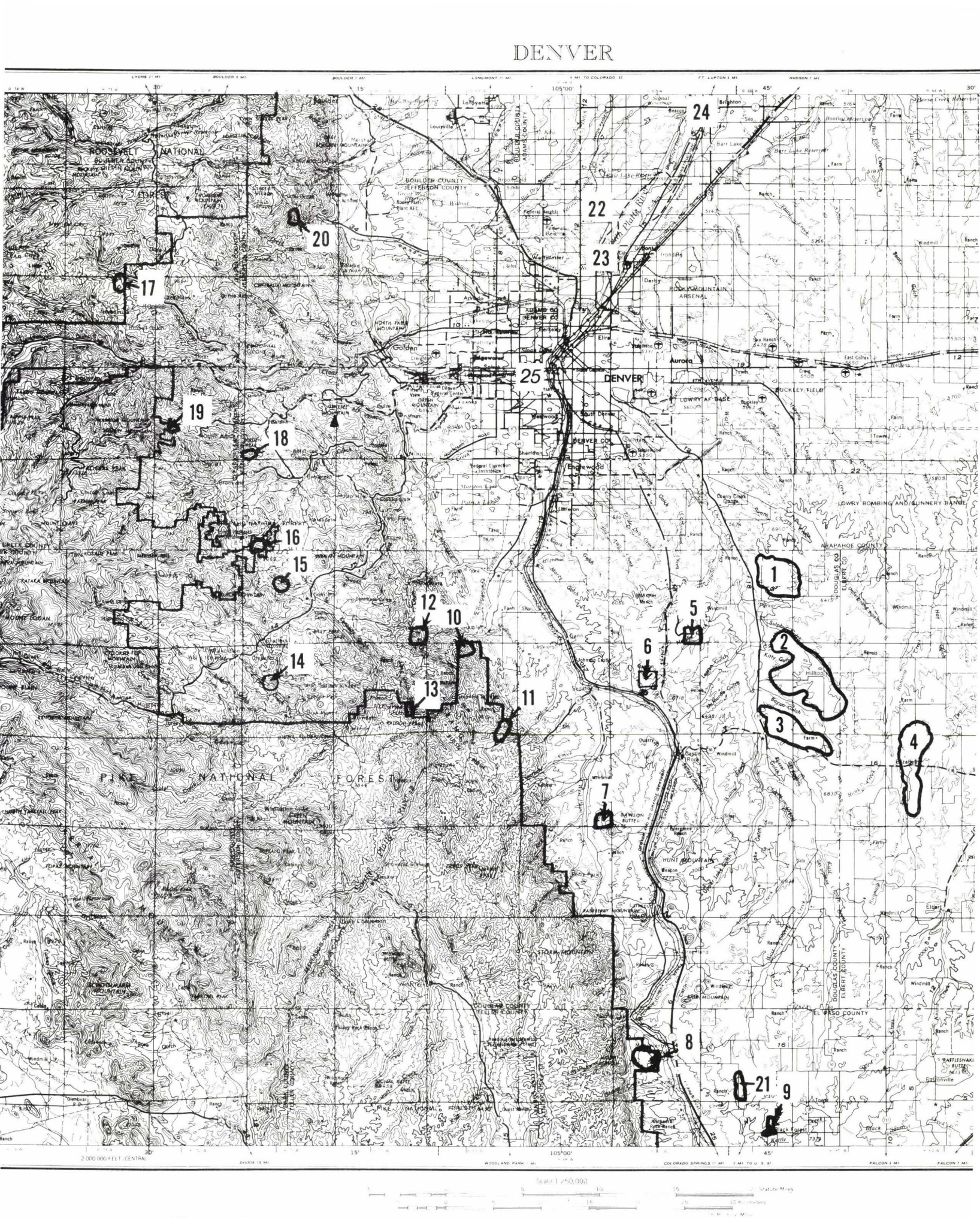

Figure 2. Location of survey areas on which ponderosa pines were examined for air pollution symptoms.

FIGURE 3. Ponderosa pine southeast of Denver displaying shortened needles and reduced needle complement similar to symptoms of oxidant air pollution injury.

FIGURE 4. Comparison of healthy ponderosa pine (on the left) with adjacent tree displaying symptoms characteristic of oxidant air pollution injury. Trees were located southeast of Denver.

FIGURE 5. Chlorotic banding on ponderosa pine needles from a tree southeast of Denver.

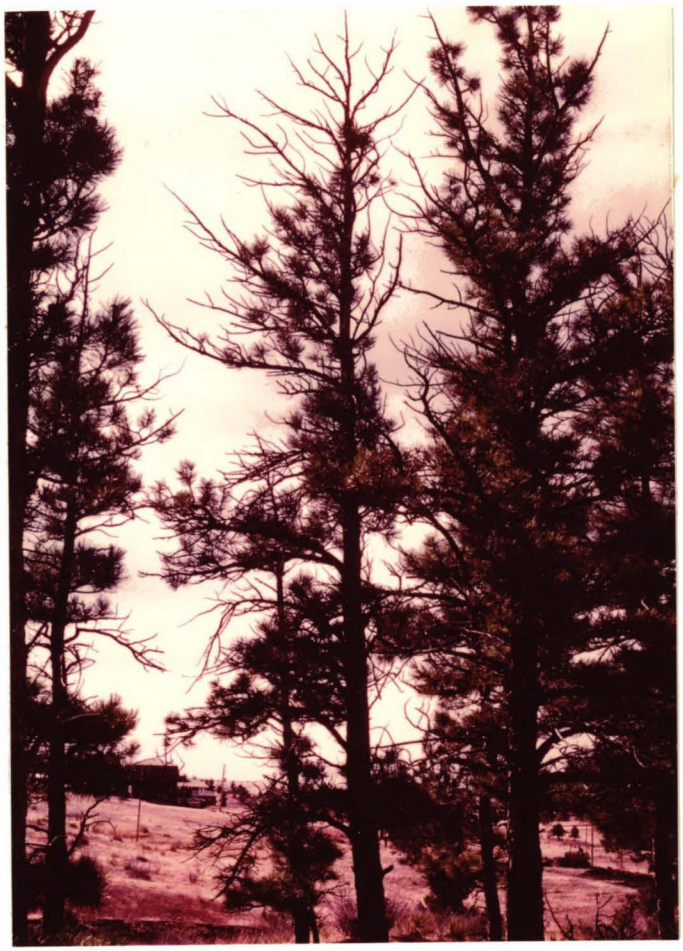

FIGURE 6. Severe dieback of ponderosa pine near Franktown, Colorado.

RESULTS

Field surveys were conducted during 1978 and 1979; very few examined trees displayed typical oxidant air pollution symptoms (Table 1). Most trees with injured foliage were southeast of Denver. Common symptoms included shortened needles and reduction of needle complement (Figs. 3 & 4). Some trees retained needles for only 1-3 years; normal retention for ponderosa pine is 4-6 years (17). Chlorotic mottle typical of oxidant-dmaaged trees in California was not found. However, chlorotic banding (Fig. 5) was common. Several trees near Franktown displayed severe dieback (Fig. 6). Aphid and needle miner activity was found on many trees; some trees were also infested with mountain pine beetles and dwarf mistletoe.

The continuing evaluation plots were located near Monument on the Pike National Forest, within the Genesee area of the Denver Regional Parks, on Table Mesa in Boulder adjacent to the National Center for Atmospheric Research in Boulder, and on the Black Forest County Park in El Paso County. Although some trees within plots received oxidant scores indicating slight air pollution injury, average plot scores indicated overall healthy conditions. Descriptions of plot locations and tree characteristics are included in the Appendix.

DISCUSSION

Photochemical air pollution from large urban areas can adversely affect forest ecosystems. Although forests near large population centers are more prone to damage, long distance spread of pollutants and resultant damage to vegetation has been reported (87). Oxidant air pollution has especially caused severe damage to forests in the San Bernardino Mountains of southern California. Prolonged exposure to high pollutant levels for many years has caused dramatic ecological effects in these mixed-conifer forests (16, 18, 26).

Ponderosa pine is highly susceptible to oxidant injury in the San Bernardino Mountains (19, 21). However, we did not encounter widespread oxidant damage to pine adjacent to Denver. Isolated trees southeast of Denver exhibited reduced needle length and retention, although distinctive chlorotic mottle was not apparent. The Rocky Mountain variety of ponderosa pine may be more resistant to oxidant injury than the coastal form. Differences in varietal susceptibility have been previously reported (4, 6). Preliminary fumigation experiments revealed that ponderosa pine from the Colorado Front Range was not damaged as much as the southern California variety when exposed to ozone (P. R. Miller, *personal communication*).

Our results may also indicate that levels of air pollution reaching the areas surveyed are not high enough to cause widespread injury. Although oxidant levels within Denver are sufficient to cause injury (1, 3, 19, 27), levels in nearby forest areas are unknown because of lack of monitoring. Prevailing westerly winds tend to carry most pollution east of Denver, away from forested areas (3). However, a monitoring program is planned to ascertain how much oxidant pollution is reaching these forests.

Air pollution damage has been found on different plant species in and around Denver. For example, well-defined necrotic lesions have been found on Bel W-3 tobacco, a variety sensitive to ozone. A characteristic injury of petunia caused by PAN [3/] has also been noted. Oxidant symptoms have also been found on certain agricultural crops northeast of Denver (R. Kohut, *personal communication*). However, no previous reports of air pollution damage to trees in the area have been made. Investigations of possible air pollution-induced tip burn of pine needles in Denver implicated chloride toxicity as the cause (23, 24).

Controlled experimentation coupled with an expanded monitoring program is needed to verify that injury to ponderosa pine foliage is actually caused by oxidant air pollution. For example, excluding ambient oxidants from portions of foliage in the field may be used to ascertain differences in response (19). Also, fumigation to identify injury thresholds and selection of sensitive indicator plants would be useful. Histopathological examination of damaged needle tissue may aid in ascertaining causes of injury. Without such studies, conclusions regarding air pollution effects on pine around Denver cannot be made.

Photochemical air pollution has been shown to predispose trees to attack by bark beetles (25) and root pathogens (7). Also, reduced tree vigor and growth without apparent symptoms has been documented (4, 14). Therefore, tree mortality caused by biotic agents may increase in environments exposed to air pollution. Although these subtle effects are difficult to establish experimentally, they may be very important ecologically.

This survey was a preliminary effort to record the current situation and evaluate the potential for air pollution damage to ponderosa pine around Denver. Our evaluation plots should provide useful information on changes (if any) in foliar injury over time.

[3/] PAN - peroxyacetyl nitrate, a component of photochemical air pollution.

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APPENDIX

Characteristics used for scoring oxidant air pollution injury on ponderosa pine (Designed by Dr. P. R. Miller).

	Score
Needle Retention (Number of years retained)	
Upper Crown	0-6
Lower Crown	0-6
Needle Condition (One score value given to each annual whorl)	
Upper Crown	
Green	4
Chlorotic Mottle	2
Uniform Yellow or Necrosis	0
Lower Crown	
Green	4
Chlorotic Mottle	2
Uniform Yellow or Necrosis	0
Needle Length (Upper and lower crown)	
Average Expected Length	1
Less than Expected Length	0
Branch Mortality (Lower crown)	
Normal Mortality	1
Pronounced Mortality	0

Score Totals:		
0	-	Dead
1 - 8	-	Very Severe Damage
9 - 14	-	Severe Damage
15 - 21	-	Moderate Damage
22 - 28	-	Slight Damage
29 - 35	-	Very Slight Damage
36 +	-	No visible Symptoms

Ozone injury scoring system developed by Pronos et al.

INDIVIDUAL TREE SCORE	YOUNGEST NEEDLES WITH SYMPTOMS	AVERAGE PLOT SCORE	EXTENT OF INJURY
0	Current Year	0 - 0.9	Very severe
1	Second Year	1.0 - 1.9	Severe
2	Third Year	2.0 - 2.9	Moderate
3	Fourth Year	3.0 - 3.9	Slight
4+*	Fifth & Older	4.0+	Very severe
4*	None	4.0	No symptoms

* These ratings were modified for the Rocky Mountain area as follows:

4	Fifth year (or none)	4.0 - 4.9	Very slight
5	Sixth year (or none)	5.0 - 5.9	No symptoms

Trees that score 4 or higher are considered healthy.

Evaluation Plot Characteristics

A. Monument

a. Location: NE 1/4, SW 1/4, Section 16, T. 11 S., R. 67 W.
b. Number of trees on plot: 30
c. Average DBH: 10.2"
d. Average height: 28.9'
e. Oxidant Injury Score
   (1) Average upper crown needle retention: 4.4 years
   (2) Average lower crown needle retention: 3.6 years
   (3) Average oxidant score: 38.7 (Miller) Range: 21-49

B. Genesee

a. Location: SE 1/4, SE 1/4, Section 11, T. 4 S., R. 71 W.
b. Number of trees on plot: 30
c. Average DBH: 14.3"
d. Average height: 38.6'
e. Oxidant Injury Score
   (1) Average upper crown needle retention: 4.2 years
   (2) Average lower crown needle retention: 3.6 years
   (3) Average oxidant score: 36.3 (Miller) Range: 24-49

C. National Center for Atmospheric Research (NCAR)[1]

a. Location: Adjacent to the National Center for Atmospheric Research at Boulder. NW 1/4, SW 1/4, T. 1 S., R. 70 W.
b. Number of trees on plot: 30
c. Average DBH: 10.25"
d. Average height: 28.0'
e. Oxidant Injury Score
   (1) Average upper crown needle retention: 4.4 years
   (2) Average lower crown needle retention: 4.0 years
   (3) Average oxidant score: 40.6 (Miller) Range: 14-49
f. Oxidant Injury Score
   (rating system of Pronos et al.): 4.0 Range: 4.0

[1] On this plot both the Miller and Pronos et al. rating systems were used. Only 25 trees were rated with the latter system.

D. Black Forest County Park

a. Location: SW 1/4, SW 1/4, Sec. 12, T. 2 S., R. 66 W.
b. Number of trees on plot: 25
c. Average DBH: 6.6"
d. Average height: N.A.
e. Oxidant Injury Score: 3.84 (rating system of Pronos et al.)
Range: 3-4

E. Genesee Mountain Park

a. Location: N 1/2, SW 1/4, Sec. 13, T. 4 S., R. 71 W.
b. Number of trees on plot: 25
c. Average DBH: 14"
d. Average height: N.A.
e. Oxidant Injury Score: 3.48 (rating system of Pronos et al.)
Range: 2-4

TABLE 1. Characteristics of ponderosa pine surveyed for symptoms of oxidant air pollution injury near Denver, Colorado.

Site Number	Site Name	Site Ownership	No. Trees Examined	Comments
1	Baldwin	Private	54	Shortened needles were found on a few trees (Fig. 3) especially near the base of trees. Foliage insect (needle miner) activity was common especially near needle tips. Needle banding was common.
2	Hilltop	Private	62	Severe chlorotic banding, shortened needles, and reduced foliage retention found on some trees near a housing development (Figs. 4 & 5). Some trees had severe aphid infestations with accompanying chlorosis.
3	Franktown	Private	57	Severe dieback occurred on many trees (Fig. 6). Shortened needles were characteristic of necrotic branches. Some trees had shortened needles and thin foliage.
4	Elizabeth	Private	54	Some trees with short needles and very few years (1-3) of needle retention, especially high in trees.
5	Newlin Gulch	Colorado State	33	Flecking was common on upper needle surface; no characteristic oxidant damage symptoms found.
6	Beacon	Colorado State	55	Some trees with shortened needles found; no other characteristic oxidant damage symptoms found.
7	Dawson Butte	Colorado State	74	No characteristic oxidant damage symptoms found.
8	Monument	Pike Nat'l Forest	87	Some trees with shortened needles, and 2-3 years retention found. Most trees had healthy, non-symtomatic foliage.
9	Black Forest	Pike Nat'l Forest	90	Heavy dwarf mistletoe; no characteristic oxidant damage symtoms found.

TABLE 1. (continued)

Site Number	Site Name	Site Ownership	No. Trees Examined	Comments
10	Kassler	Pike Nat'l Forest	45	No characteristic oxidant damage symptoms found.
11	Indian Creek	Pike Nat'l Forest	74	Two trees with thin crowns near road; no other characteristic oxidant damage symptoms found.
12	Cottonwood Gulch	Colorado State	20	Flecking was common on some foliage; no characteristic oxidant damage symptoms found.
13	Dome Rock	Pike Nat'l Forest	36	No characteristic oxidant damage symptoms found.
14	Pine Gulch	Colorado State	86	No characteristic oxidant damage symptoms found.
15	Conifer	Colorado State	74	No characteristic oxidant damage symptoms found.
16	Cub Creek	Arapaho Nat'l Forest	68	No characteristic oxidant damage symptoms found.
17	Squaw Pass	Roosevelt Nat'l Forest	76	No characteristic oxidant damage symptoms found.
18	Bergen Park	Colorado State	65	No characteristic oxidant damage symptoms found.
19	Columbine	Arapaho Nat'l Forest	52	No characteristic oxidant damage symptoms found.

TABLE 1. (continued)

Site Number	Site Name	Site Ownership	No. Trees Examined	Comments
20	Blue Mountain	Colorado State	79	No characteristic oxidant damage symptoms found.
21	Eighty Three	Private	43	Heavy porcupine damage; no characteristic oxidant damage symptoms found.
22	Northglenn	City	16	Park trees within Northglenn and Thornton City Parks; no characteristic oxidant damage symptoms found.
23	Welby	City	21	Some needle chlorosis although no mottling found; no other characteristic oxidant damage symptoms found.
24	Brighton	City	35	Park and cemetary trees within Brighton. No characteristic oxidant damage symptoms found.
25	Sloans Lake	City	26	Park trees; no characteristic oxidant damage symptoms found.

TOTAL TREES EXAMINED: 1,382